DIMENSIONAL & SURFACE ROUGHNESS ANALYSIS OF FUSED DEPOSTION MODELLING PARTS MADE OF DIFFERERNT POLYMERS

[1]Ujjaval Modi, [2]Shashi Prakash, [3]Hitesh Raiyani

[1]M.E Scholar, [2]Assistant Professor, [3]Assistant Professor
[1]Mechanical Department of Post-Graduation Section,
[1]L.J.Institute of Engineering and Technology, Ahmedabad, Gujarat, India

Abstract: Additive Manufacturing (AM) technologies have high potential in terms of productivity and competitiveness for companies, their diffusion is still relatively limited among manufactures and end users. AM technology have different categories such as Material Extrusion, VAT Photopolymerisation, Powder Bed Fusion, Material Jetting, Binder Jetting, Sheet Lamination, Directed Energy Deposition. Fused deposition modeling (FDM) under Material Extrusion category is one of the most common and widely used additive manufacturing technology. FDM process is the most versatile additive manufacturing process due to low cost range, flexibility, broad range in material, low time consumption and accessibility. A study of dimensional accuracy, surface roughness & wettability are basically depending on the process parameter such as layer thickness, build orientation, print speed and post processing methods. In this research work, dimensional accuracy, surface roughness & wettability of 3D printed ABS; PLA & PP parts have been investigated at different raster angle.

IndexTerms – Additive manufacturing, fused deposition modelling, surface roughness, dimensional accuracy, wettability.

I. INTRODUCTION

Additive Manufacturing (AM) technologies have high potential in terms of productivity and competitiveness for companies, their diffusion is still relatively limited among manufacturers and end users. The high cost of this equipment could be a key reason, but there is a general agreement that there is a lack of deep knowledge of these technologies as well as skills for implementing them in companies. [1] Additive manufacturing is also known as rapid prototyping which is used in a variety of industries to describe a process for rapidly creating a system or part representation before final release or commercialization. [2] According to many case studies[3-5], among all additive manufacturing processes, Fused deposition modelling process which is extrusion based additive manufacturing is widely used in industries because of several reason such as lower cost, broad range in material, less time consuming and easy accessibility. As mentioned about material, many materials have been used in process from which ABS, PLA and PP are mostly used. These materials are being used in several areas such as architecture, automobile, medical industries. However many problems have been raised in FDM process like surface and dimensional accuracy [8-10].

II. PROBLEM FORMULATIONS

In the FDM process, many errors have been found from different studies which are due to curing and control errors. These errors are affecting accuracy of object in terms of dimensional and surface accuracy which are most important for any object. To improve accuracy of 3D printed part either control processing parameter or introduce some post processes according to material. Layer separation error, surface warping and oozing[11], these error are happened during process which can be controlled process parameter[12-13] and improvement of dimensional and surface accuracy can be managed by post processes such as abrasive operation, laser treatment and solubility test. In this research paper, three different materials have been considered with process parameter and solubility test has been considered for improvement of accuracy.

III. MATERIAL

As mentioned early, there is broad range of materials for FDM process based machines. Among all materials, ABS, PLA and PP materials have been chosen for research work. The reason behind choosing these material is, easily available in market, can be printed complex parts with these materials with good enough strength.

PLA is a biodegradable, compostable, renewable, thermoplastic material. This polyester is made from lactic acid and as it has biodegradable property which makes it ecofriendly polymer material.[14] ABS is common thermoplastic polymer typically used for injection molding application. This engineering plastic is popular due to its low production cost and the ease with which the machined by plastic manufacturers. ABS is a non-biodegradable material so that atmosphere effect will not affect the material property.[15] Polypropylene is thermoplastic polymer made from combination of propylene monomers. It is used in various applications like consumer product packaging product, automobile industry though it’s difficult to manufacture through additive process compare to other material.[16]

IV. EXPERIMENTAL DETAILS

In this research work, PLA, ABS and PP filament having diameter of 2.85 ± 0.10 mm from a commercial filament manufacturer are being used. A commercially available 3D printer was used in this work. A sample object was designed such a way that different types if surface were included like flat surface as surface 1, free form surface as surface 2, semicircular surface as surface 3 and inclined surfaces as surface 4 & 5 as shown in figure 1.

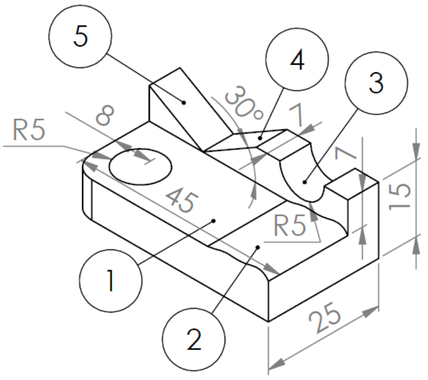

Figure 1. Designed part to be printed

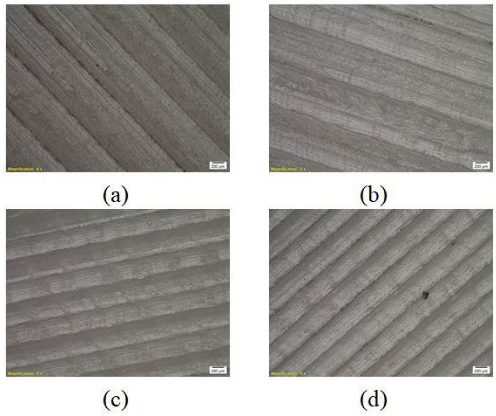

Figure 2. Microscopic image of the fiber direction for different rater angle (a) 0°, (b) 30°, (c) 60°, (d) 90°

These sample objects are printed in FDM based 3D printer from different material like ABS, PLA and PP at different build orientation about z axis varying from 0° to 90° in step of 30°. Therefore, four types of the same object have been printed with rater angle as 0°, 30°, 60° & 90°. These all objects from different material have been printed with process parameter as mentioned in table 1. Due to change in raster angles, rater pattern is different for different build orientation as shown in figure 2.

Table. 1 Printing Process input parameter

Parameter	Value
Material infill density	100%
Build plate temperature	60 °C
Nozzle temperature	210 °C
Layer thickness	0.1mm
Print speed	50 mm/s

As in additive manufacturing process, post process is mandatory as without post process, accuracy cannot be improved for any material. There are many post processes for different polymer material such as laser treatment and abrasive operation. As objects are in small size, laser treatment will not affected much in dimensional and surface accuracy. For abrasive operation, it is difficult to apply same pressure manually through whole surfaces for accuracy improvement. Overhere during process, water soluble support structure has been used. After completion of object, support material can be removed easily either by water solubility or by manually which ensure to prevent any surface breakage. Using same logic these materials are soluble in particular chemical which help to improve surface texture without interfering dimensional accuracy much. ABS, PLA and PP material is soluble in acetone, tetrahydrofuran and tetralin chemical respectively. Objects from different materials are not fully merged into these chemical, instead of that, objects were polished by these chemicals with help of cotton manually. Due to chemical effect with polymer, surface texture was improved as mentioned in tables. In every result table, left side (without prime) data for any surface or angle were denoted measurement before chemical treatment while right side (with prime) were denoted measurement after chemical treatment.

V. RESULT AND DISCUSSION

Surface roughness often shortened to roughness, is a component of surface texture. It is quantified by the deviations in the direction of the normal vector of a real surface from its ideal form. If deviations are large, the surface is rough; if they are small, the surface is smooth. In this research work, surface roughness is measured by SURFTEST SJ-210 SERIES from MItutoyo.

Table. 2 Ra parameter for different surface before and after chemical treatment

Material	Raster angle	Surfaces									
		Ra in µm									
		1	1’	2	2’	3	3’	4	4’	5	5’
ABS	0	3.598	2.367	0.248	0.134	5.982	3.342	4.334	2.435	3.153	1.345
	30	0.975	0.345	0.370	0.135	3.121	2.341	2.321	1.346	2.513	1.456
	60	1.590	0.453	0.454	0.254	3.604	2.124	2.532	1.356	3.432	1.634
	90	2.292	1.234	0.692	0.238	4.320	2.531	3.231	1.754	2.453	1.436
PLA	0	1.959	1.123	0.272	0.146	3.016	1.564	1.982	0.346	1.421	0.346
	30	1.127	0.345	0.689	0.124	2.731	1.574	2.017	1.034	2.417	1.245
	60	1.570	0.235	0.357	0.214	3.068	1.785	2.125	1.345	2.145	0.452
	90	2.008	1.324	0.547	0.325	4.503	2.574	2.964	1.356	1.964	0.252
PP	0	6.582	4.234	2.597	1.354	14.836	10.235	5.213	2.453	3.642	1.342
	30	7.725	3.465	21.287	16.523	11.777	6.345	5.980	2.325	3.764	1.325
	60	4.932	2.352	22.483	15.421	11.588	7.425	4.212	2.145	4.252	2.141
	90	1.437	0.235	5.986	2.455	13.911	8.342	3.134	1.352	3.142	1.745

Table. 3 Rz parameter for different surface before and after chemical treatment

Material	Raster angle	Surfaces									
		Rz in µm									
		1	1'	2	2'	3	3'	4	4'	5	5'
ABS	0	18.679	9.435	1.676	0.233	32.566	13.534	5.234	2.754	4.521	2.463
	30	6.481	2.235	2.221	1.422	19.248	9.234	4.234	2.143	4.235	2.456
	60	11.949	5.235	3.073	1.934	19.006	10.342	5.124	2.453	5.235	2.453
	90	12.385	5.763	3.990	1.892	27.434	15.352	2.534	1.352	3.452	1.894
PLA	0	10.055	4.463	1.830	0.643	15.707	8.234	4.234	2.143	4.253	1.755
	30	7.090	3.346	3.132	2.124	14.307	5.324	3.513	1.634	2.653	1.954
	60	8.543	3.463	2.004	1.463	16.663	8.213	4.313	2.124	6.235	2.464
	90	9.392	4.235	3.047	1.934	26.467	16.235	5.234	2.352	2.514	1.463
PP	0	65.245	20.346	18.353	5.135	138.16	40.235	2.235	0.976	5.325	2.463
	30	52.760	32.235	151.96	42.522	89.589	35.234	5.235	2.351	2.523	1.363
	60	47.522	23.345	157.55	40.341	95.133	46.235	2.523	1.235	3.515	1.683
	90	13.045	5.452	61.528	20.352	84.059	34.234	5.235	2.345	3.513	1.456

(b)

Dimensional accuracy is important parameter for any object. In this research work, many tolerances parameters have been considered such as parallelism, roundness, cylindricity, angularity. These parameters have been measured in co-ordinate measuring machine (CMM) from Carl Ziess make. As shown in table 4, 5 & 6, for parallelism four out plane have been considered while perpendicularity, all plane with perpendicular plane have been considered and for cylindricity, three cylinder are considered and last for angularity, both inclined planes are considered for measurement.

Table 4. Dimensional measurement for ABS material before and after chemical treatment

Geometric tolerance in mm	Raster angle in degree							
	0	0'	30	30'	60	60'	90	90'
Parallelism 1	0.0449	0.0395	0.4586	0.3532	0.0985	0.0873	0.1099	0.0934
Parallelism 2	0.1709	0.1674	0.3272	0.2932	0.3877	0.3134	0.1708	0.1583
Perpendicularity 1	0.1029	0.0923	0.4469	0.4292	0.1298	0.1103	0.0558	0.0478
Perpendicularity 2	0.1097	0.0894	0.3229	0.3042	0.5133	0.4902	0.2669	0.1935
Perpendicularity 3	0.1166	0.1093	0.0628	0.0534	0.0992	0.0873	0.0579	0.0463
Perpendicularity 4	0.2118	0.2012	0.1372	0.1042	0.1103	0.1034	0.2249	0.2143
Cylindricity 1	0.0841	0.0783	0.0991	0.0842	0.0472	0.0341	0.1481	0.1323
Cylindricity 2	0.0577	0.0464	0.0355	0.0254	0.0295	0.0234	0.0289	0.0214
Cylindricity 3	0.1614	0.1574	0.0561	0.0475	0.0852	0.0784	0.0091	0.0083
Angularity 1	0.0079	0.0069	0.0284	0.0214	0.0157	0.0134	0.0133	0.0103
Angularity 2	0.0494	0.0373	0.0817	0.0784	0.0106	0.0089	0.0515	0.0432

Table 5. Dimensional measurement for PLA material before and after chemical treatment

Geometric tolerance in mm	Raster angle in degree							
	0	0'	30	30'	60	60'	90	90'
Parallelism 1	0.3349	0.2901	0.4218	0.3654	0.4363	0.3534	0.5281	0.5034
Parallelism 2	0.7640	0.6834	0.6030	0.5034	0.7398	0.6453	0.7161	0.6745
Perpendicularity 1	0.2522	0.2135	0.7846	0.6843	0.6056	0.5342	0.6847	0.6234
Perpendicularity 2	0.9983	0.8945	0.6957	0.6323	0.7654	0.6342	1.0331	0.0945
Perpendicularity 3	0.4552	0.4132	0.3264	0.3034	0.3681	0.3351	0.3560	0.3423
Perpendicularity 4	1.0931	0.9423	0.7931	0.7123	1.0764	0.0754	0.8628	0.7545
Cylindricity 1	0.1095	0.9342	0.0869	0.0783	0.0775	0.0345	0.1083	0.0942
Cylindricity 2	0.0559	0.0478	0.0867	0.0789	0.0424	0.0234	0.0346	0.0242
Cylindricity 3	0.3670	0.2903	0.0486	0.0342	0.0075	0.0065	0.0176	0.0124
Angularity 1	0.0262	0.0164	0.0255	0.0134	0.0019	0.0013	0.0154	0.0134
Angularity 2	0.0629	0.0584	0.0773	0.0678	0.0684	0.0453	0.0877	0.0243

Table 6. Dimensional measurement for PP material before and after chemical treatment

Geometric tolerance in mm	Raster angle in degree							
	0	0'	30	30'	60	60'	90	90'
Parallelism 1	0.3302	0.2342	0.3567	0.2343	0.6494	0.4234	0.5158	0.4234
Parallelism 2	0.2251	0.1422	0.2256	0.1432	0.3172	0.2545	0.5687	0.2343
Perpendicularity 1	0.7052	0.5453	0.6175	0.5342	1.1278	0.9342	1.0375	0.5452
Perpendicularity 2	0.0555	0.0345	0.2463	0.1533	0.8961	0.4523	0.0395	0.0245
Perpendicularity 3	0.1201	0.0934	0.1354	0.1034	0.2162	0.1342	0.1183	0.0934
Perpendicularity 4	0.2172	0.1543	0.3461	0.2543	0.6290	0.4234	1.0387	0.5232
Cylindricity 1	0.5803	0.4234	0.4795	0.2453	0.2875	0.1452	0.3401	0.2523
Cylindricity 2	0.0869	0.0634	0.0561	0.0245	0.0914	0.0832	0.0943	0.0634
Cylindricity 3	0.0913	0.0634	0.0811	0.0634	0.0601	0.0532	0.0838	0.0532
Angularity 1	0.0136	0.0123	0.5339	0.4524	0.2425	0.1345	0.2130	0.1435
Angularity 2	0.1875	0.1264	0.4709	0.3423	0.0805	0.0423	0.0864	0.0634

(e)

Last property for research is wettability. It is the tendency of one fluid to spread on, or adhere to, a solid surface in the presence of other immiscible fluids. Wettability refers to the interaction between fluid and solid phases. In a reservoir rock the liquid phase can be water or oil or gas, and the solid phase is the rock mineral assemblage. Here wettability for the surfaces was measured using kyowa contact angle. Water droplets were dropped from the attached syringe and dynamic response was measured on software provided by the machine manufacturer on a workstation. In the experiment distilled water has been used. Each reading was taken at three times and their arithmetical average was taken as the contact angle indicator. Water droplets were dropped at the center point of each surface for each rater orientation.

Table 7. Contact angle in degree for ABS material before and after chemical treatment

Raster angle	Surfaces									
	1	1'	2	2'	3	3'	4	4'	5	5'
0°	63.6°	48.3°	57.2°	32.8°	83.6°	54.8°	89.9°	59.5°	92.9°	56.3°
30°	62.3°	53.2°	60.7°	49.3°	75.1°	43.5°	99.3°	68.4°	94.8°	60.4°
60°	58.0	39.3°	55.3°	32.5°	67.4°	39.6°	105.4°	60.4°	84.2°	49.3°
90°	48.2°	29.4°	46.8°	32.5°	38.7°	29.8°	114.9°	74.3°	75.3°	40.3°

Table 8. Contact angle in degree for PLA material before and after chemical treatment

Raster angle	Surfaces									
	1	1'	2	2'	3	3'	4	4'	5	5'
0°	43.4°	23.5°	54.7°	34.2°	39.5°	21.4°	75.0°	38.4°	77.5°	34.2°
30°	41.6°	29.4°	49.1°	28.4°	13.4°	9.3°	77.6°	41.4°	74.5°	39.3°
60°	55.0°	32.2°	63.4°	32.7°	74.4°	36.3°	95.6°	54.2°	91.3°	52.5°
90°	65.0°	37.4°	74.5°	41.5°	77.5°	41.5°	83.1°	39.2	94.0°	53.7°

Table 9. Contact angle in degree for PP material before and after chemical treatment

Raster angle	Surfaces									
	1	1'	2	2'	3	3'	4	4'	5	5'
0°	58.3°	26.6°	67.3°	32.5°	43.4°	17.4°	64.4°	28.4°	68.3°	29.4°
30°	42.6°	34.5°	62.5°	29.5°	63.5°	35.3°	78.4°	32.5°	52.4°	31.3°
60°	47.6°	32.7°	43.5°	21.4°	64.5°	39.3°	54.6°	29.4°	64.5°	28.5°
90°	53.6°	25.3°	53.6°	27.3°	78.4°	47.4°	58.4°	27.5°	73.5°	35.4°

(h)

VI. CONCLUSION

From the above discussion it can be concluded that surface roughness and wettability of object can be improved with help of chemicals for different polymer material without affecting much into dimensional accuracy. Another conclusion from the data is, for any application, particular surface roughness and wettability is needed, process parameters with material can be chosen easily accordingly.

VII. ACKNOWLEDGEMENT

We take this opportunity to express our gratitude to our loving parents who are the centre of our inspiration.

REFERENCES

[1] Additive Manufacturing – Developments in training and education by Eujin Pei, Mario Monzon, Alain Bernard; Springer
[2] Additive Manufacturing Technologies by Ian Bibson, David W. Rosen, Brent Stucker; Spronger
[3] https://www.ukessays.com/essays/engineering/history-impact-additive-manufacturing-2691.php
[4] https://manufactur3dmag.com/7-types-additive-manufacturing-technologies/
[5] Sung-hoon ahn , "The effects of moisture and temperature on the mechanical properties of additive manufacturing components: Fused deposition modeling." Rapid prototyping journal, 2016
[6] Vijeth reddya, olena flysa,b, anish chaparalaa, chihab e berrimia, amogh va, bg rosena, "Study on surface texture of fused deposition modeling.", 8th swedish production symposium, 2018, stockholm, Sweden
[7] assimo martorelli, salvatore gerbino, antonio lanzotti, stanislao patalano, "Flatness, circularity and cylindricity errors in 3D printed models associated to size and position on the working plane" , 2017
[8] O.s. carneiro, a.f. silva, r. Gomes, "Fused deposition modeling with polypropylene", Materials & design 83, 2015
[9] A. Jord-vilaplana, v. Fombuena, d. García-garcía, m.d. samper, l. Sánchez-nácher, "Surface modification of polylactic acid (PLA) by air atmospheric plasma treatment", European polymer journal 58, 2014
[10] Ashu garg, anirban bhattacharya and ajay batish, "On Surface Finish and Dimensional Accuracy of FDM Parts after Cold Vapor Treatment", Materials and manufacturing processes, 2015
[11] M.n. sudin, shamsul anuar shamsudin, mohd azman Abdullah, "Effect of part features on dimensional accuracy of fdm model" Journal of engineering and applied sciences, 2016
[12] Habibur rahman, dr. T. D. John, sivadasan. M, dr. N. K singh, "Investigation on the Scale Factor applicable to ABS based FDM Additive Manufacturing", International conference on processing of materials, minerals and energy, 2016
[13] Dudescu cristian, racz laszlo , "Effects of raster orientation, infill rate and infill pattern on the mechanical properties of 3d printed materials" Acta uiversitatis cibiniensis – technical series vol. Lxix, 2017
[14] Nadir Ayrilmis, "Effect of layer thickness on surface properties of 3D printed materialsproduced from wood flour/PLA filament", Polymer testing 71 (2018) 163-166
[15] https://www.designtechsys.com/articles/working-fdm-3d-printers
[16] https://www.plasticextrusiontech.net/resources/what-is-abs-material/